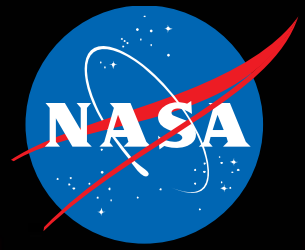
National Aeronautics and Space Administration



Cloudy with a Chance of Solar Flares:
The Sun as a Natural Hazard

Jonathan Pellish, Ph.D.

NASA Goddard Space Flight Center
Greenbelt, MD USA

February 2017

www.nasa.gov

To be released on http://www.aaas.org/.

Background image courtesy of NASA/SDO and the AIA, EVE, and HMI science teams.

Acknowledgements

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  - Heliophysics Science Division, NASA Goddard Space Flight Center
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- Supported in part by:
  - NASA Electronic Parts and Packaging (NEPP) Program
  - NASA Goddard Space Flight Center Strategic Collaboration Initiative

Space Weather – *What Is It and Why Care?*

- Space Weather
  - *"conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health."*

  [US National Space Weather Program]
- <Space> Climate
  - "*The historical record and description of average daily and seasonal <space> weather events that help describe a region. Statistics are usually drawn over several decades*."

  [Dave Schwartz the Weatherman – Weather.com]

"Space weather" refers to the dynamic conditions of the space environment that arise from emissions from the Sun, which include solar flares, solar energetic particles, and coronal mass ejections.

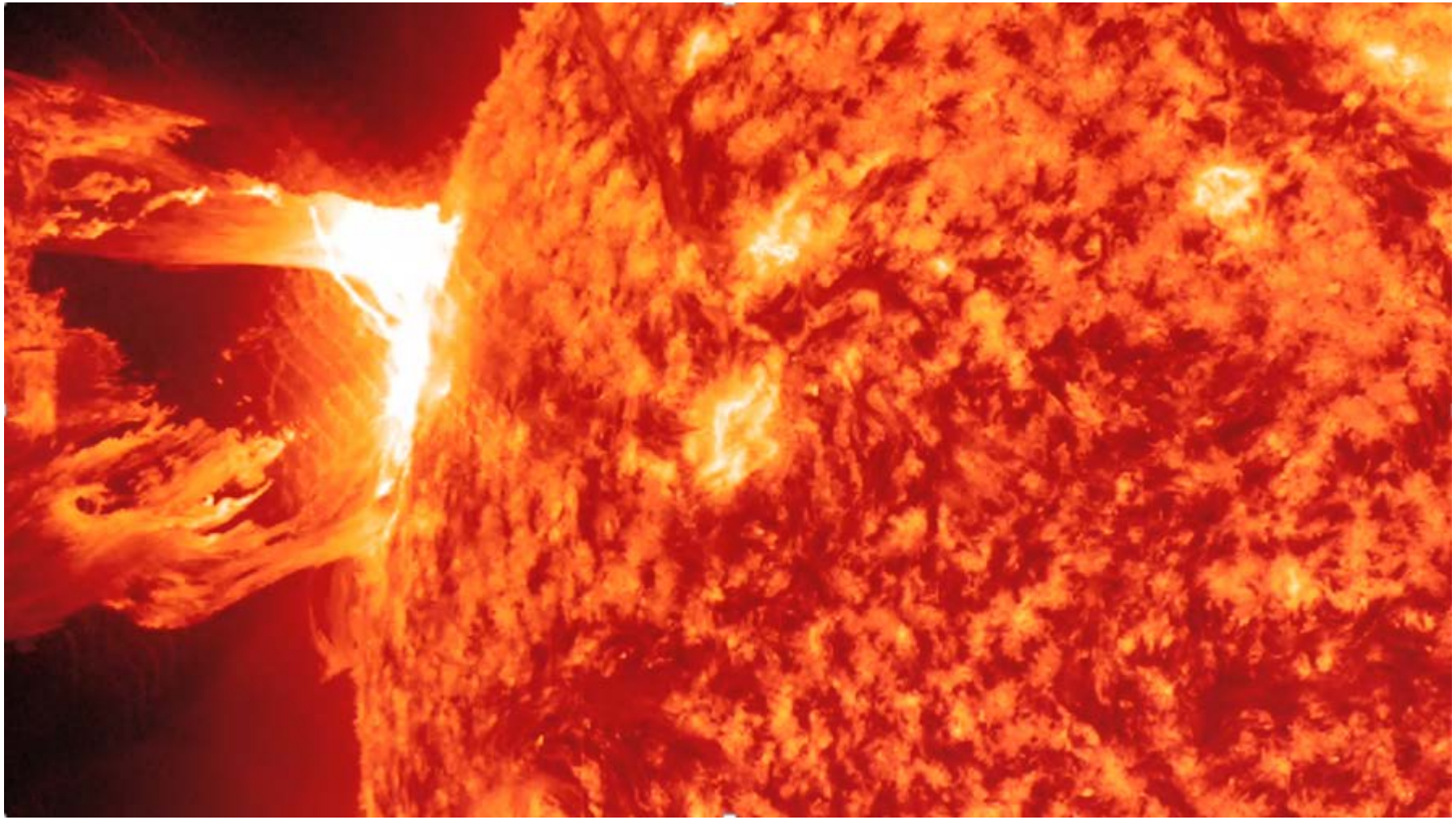
These emissions can interact with Earth and its surrounding space, including the Earth's magnetic field, potentially disrupting […] technologies and infrastructures.

National Space Weather Strategy,
Office of Science and Technology Policy,
October 2015

To be released on http://www.aaas.org/.

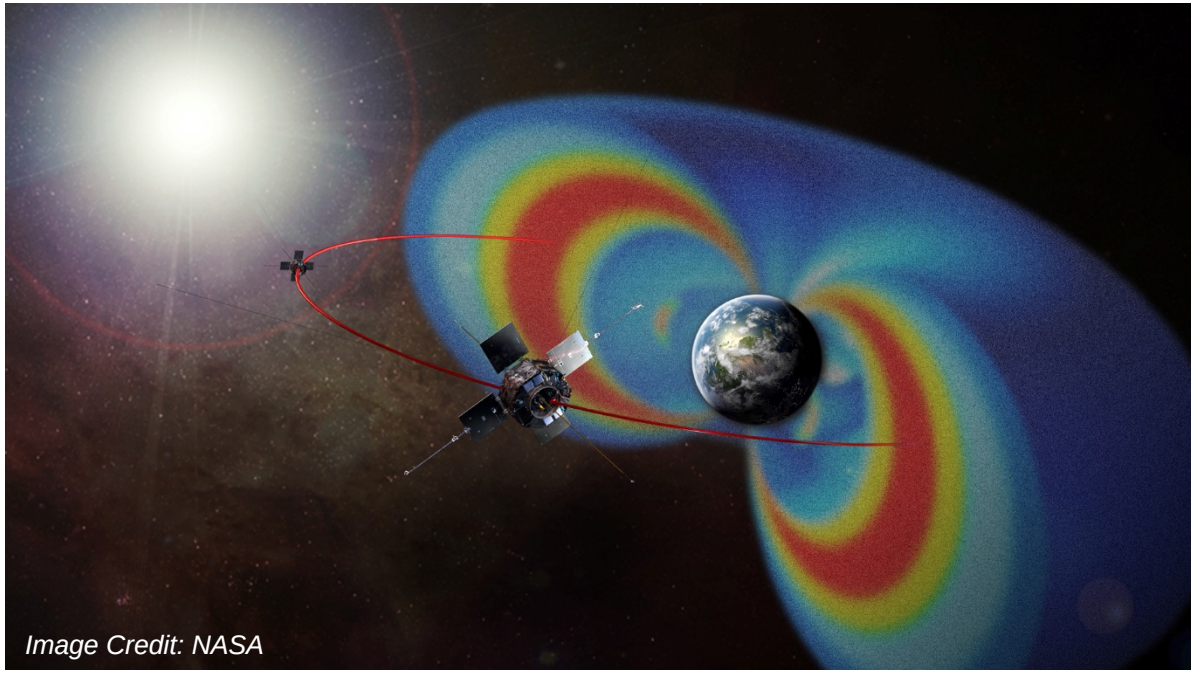
The Sun Produces Some Big Events

Coronal mass ejection shot off the east limb (left side) of the sun on Apr. 16, 2012



NASA/Goddard Space Flight Center/SDO

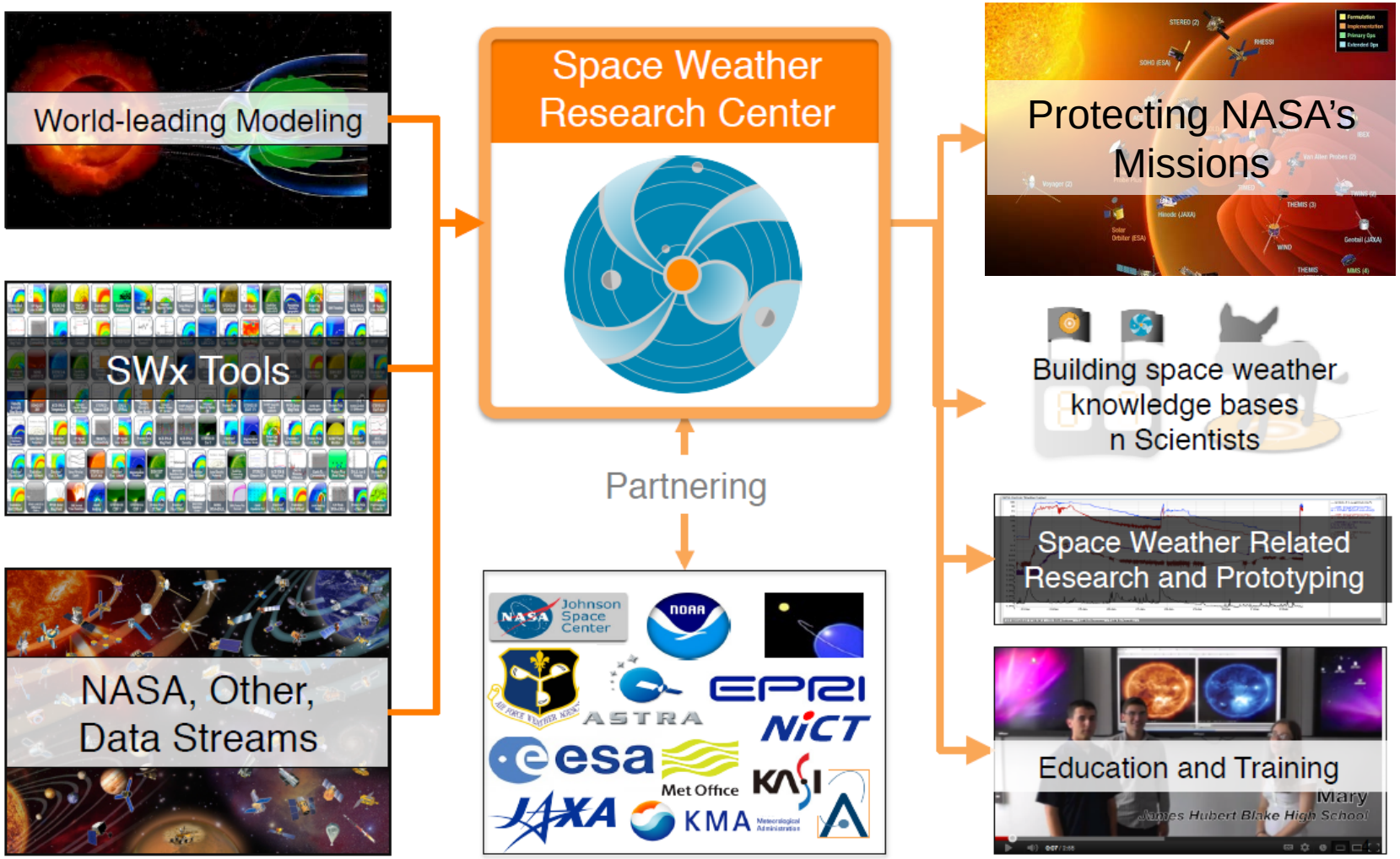
Space Weather – a NASA Point of View



Artist's rendering of the Van Allen Probes mission shows the path of its two spacecraft through the radiation belts that surround Earth, which are made visible in false color.

- NASA is the lead US agency for research of the space environment
- NASA collaborates with other agencies, industry, academia and our international partners to transition research to societal benefit
- NASA itself has unique space weather needs, in particular for human space flight, missions with specific science purposes, and missions that venture far beyond Earth's orbit

NASA Goddard Space Weather Research Center Concept of Operations

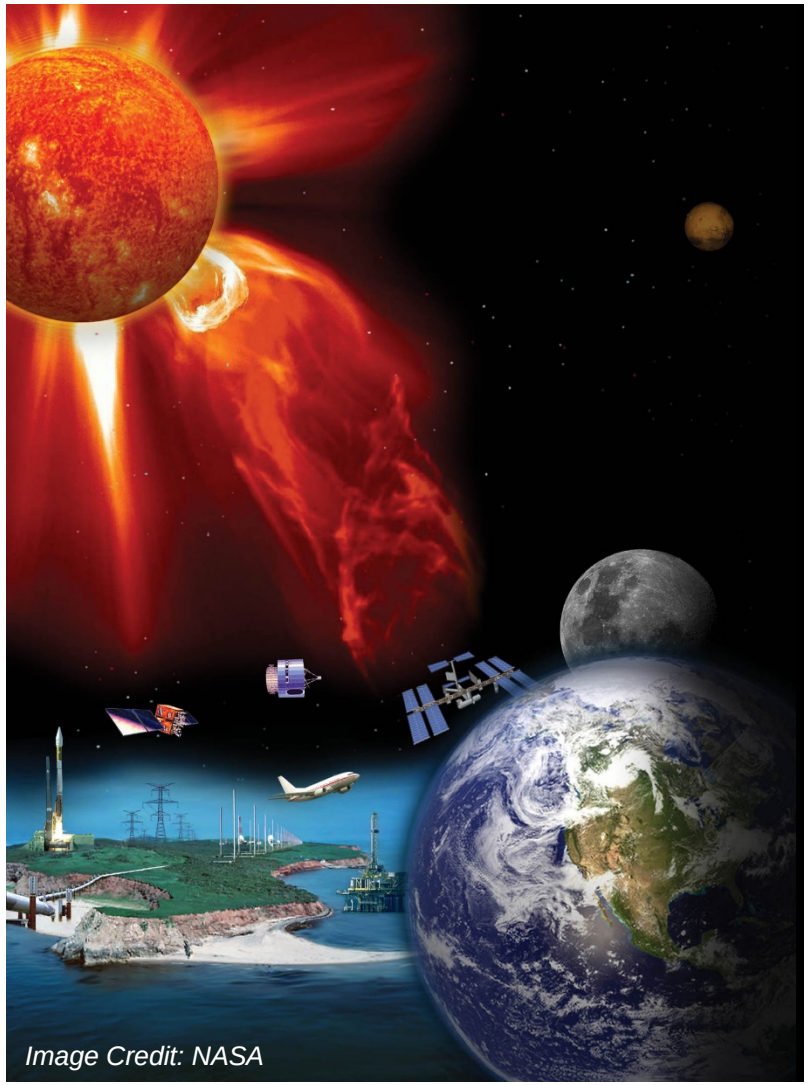


https://swrc.gsfc.nasa.gov/ https://ccmc.gsfc.nasa.gov/

A. Pulkkinen, 6th Annual Space Weather Workshop, Greenbelt, MD, 2014.

Sun-Earth Connection

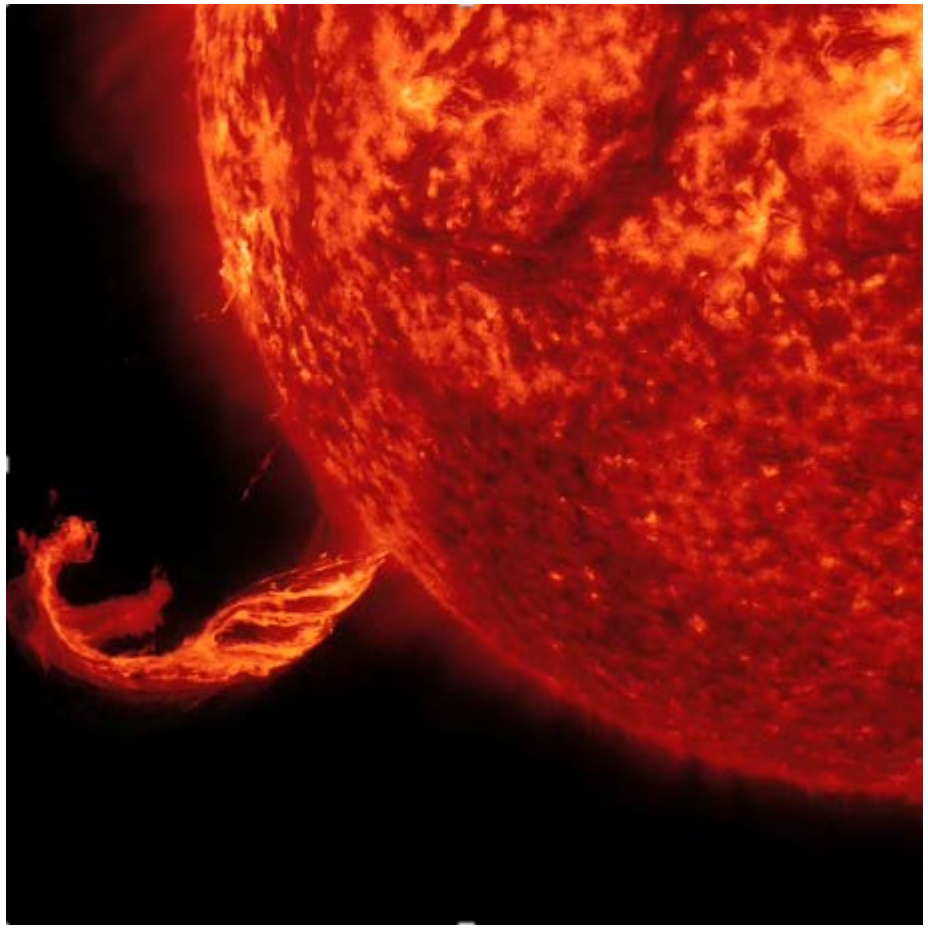
- Space weather is driven by changes in the Sun's magnetic field and by the consequences of that variability in Earth's magnetic field and upper atmosphere.
  - Space weather is generally mild but some times extreme.
  - Societal interest in space weather grows rapidly.
  - Space weather is an international challenge.
  - Mitigating against the impacts of space weather can be improved.
  - Existing observatories that cover much of the Sun–Earth system provide a unique starting point.



C. J. Schrijver, *et al.*, *Adv. Space Res.,* vol. 55, no. 12, pp. 2745-2807, 2015.

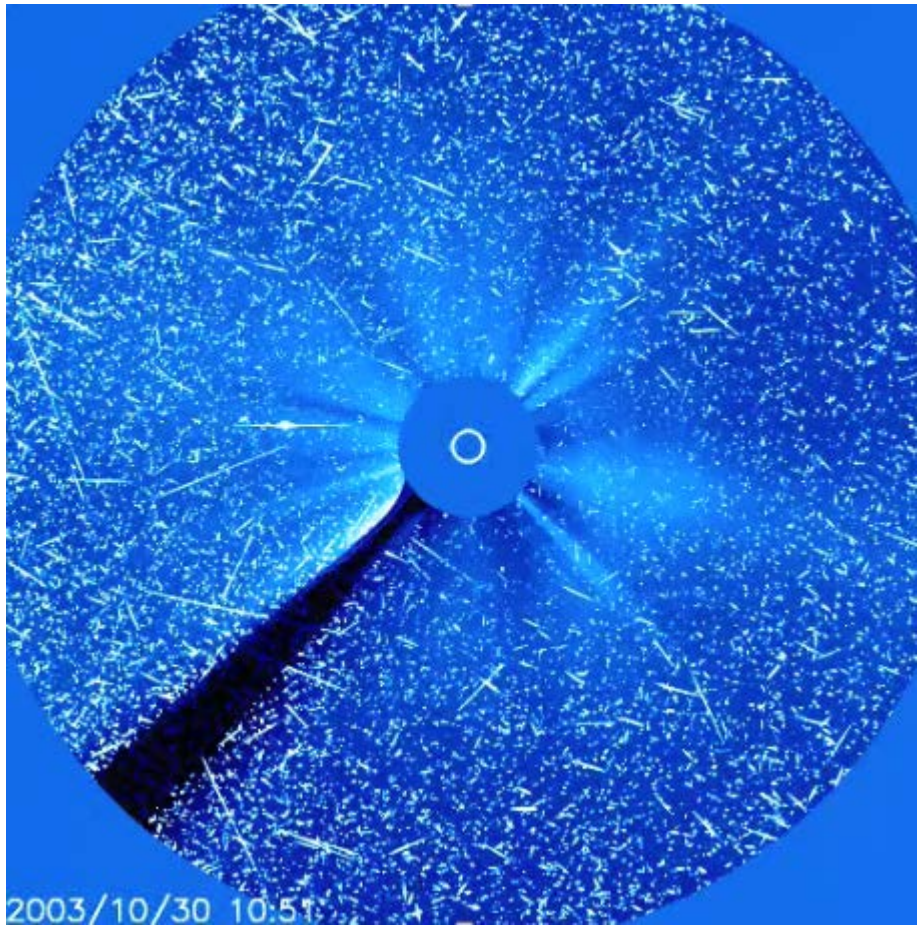
The Sun Controls Space Weather

Coronal Mass Ejection and Filament (Feb. 24, 2015)



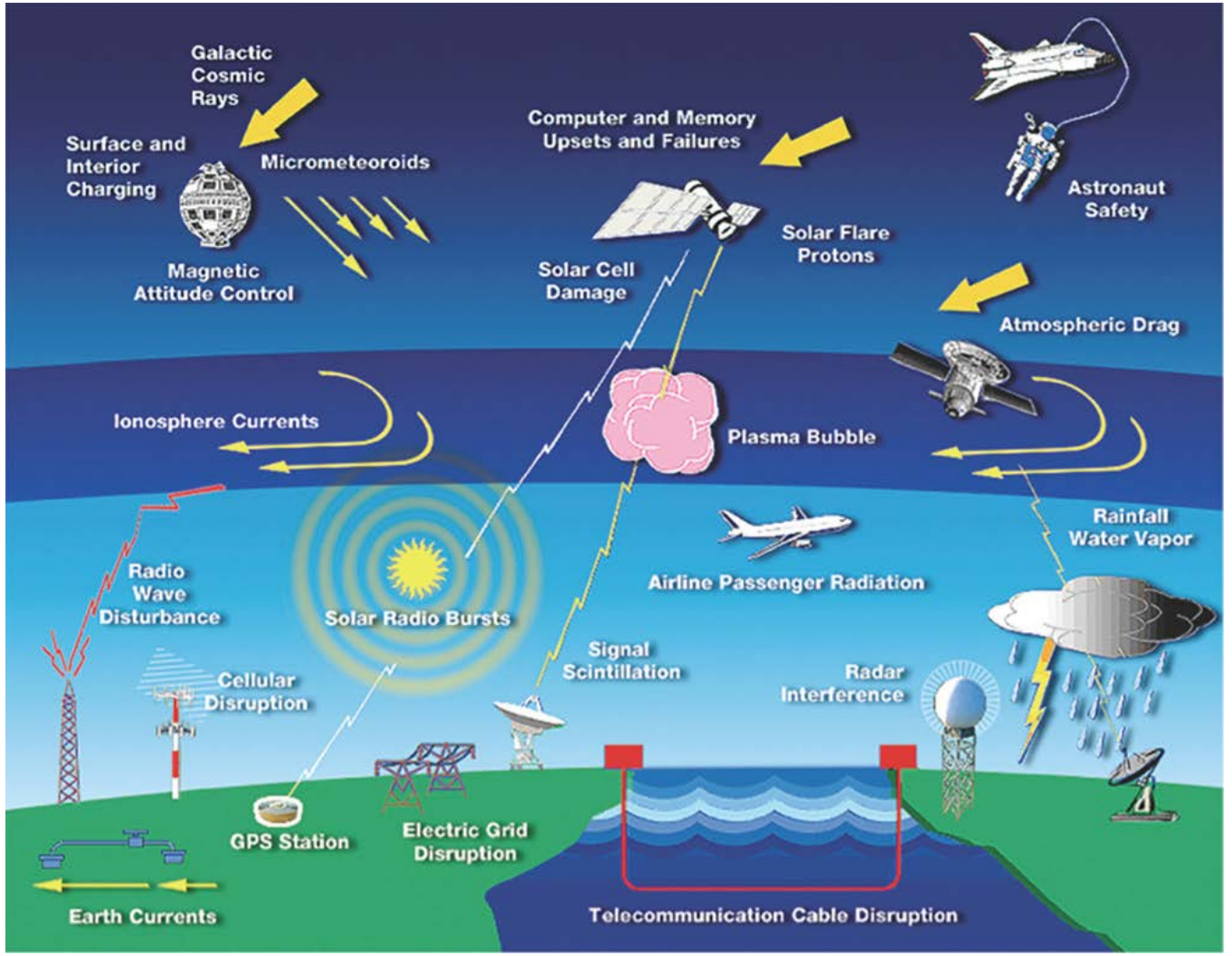
Courtesy of NASA/SDO and the AIA, EVE, and HMI science teams.

Halloween Storms (Oct. 18 - Nov. 7 2003)



Courtesy of SOHO/LASCO consortium. SOHO is a project of international cooperation between ESA and NASA.

Potential Space Weather Hazards

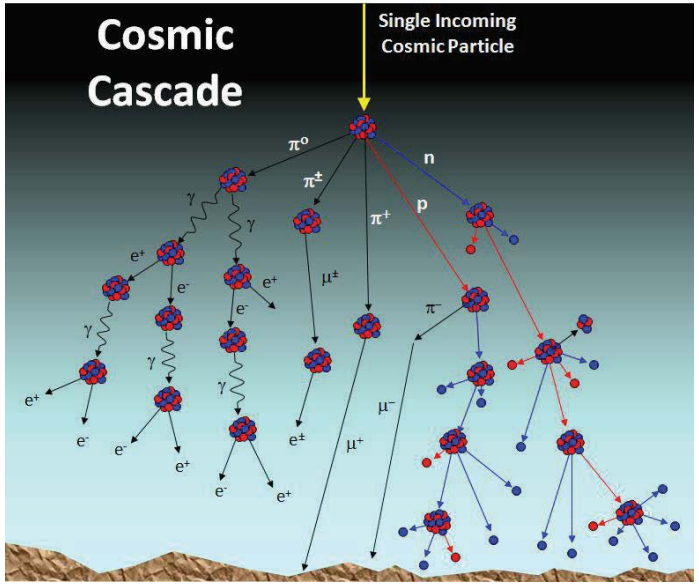


D. N. Baker, and L. J. Lanzerotti, "Resource Letter SW1: Space Weather," *Am. J. Phys.,* vol. 84, no. 3, pp. 166-180, 2016.

To be released on http://www.aaas.org/.

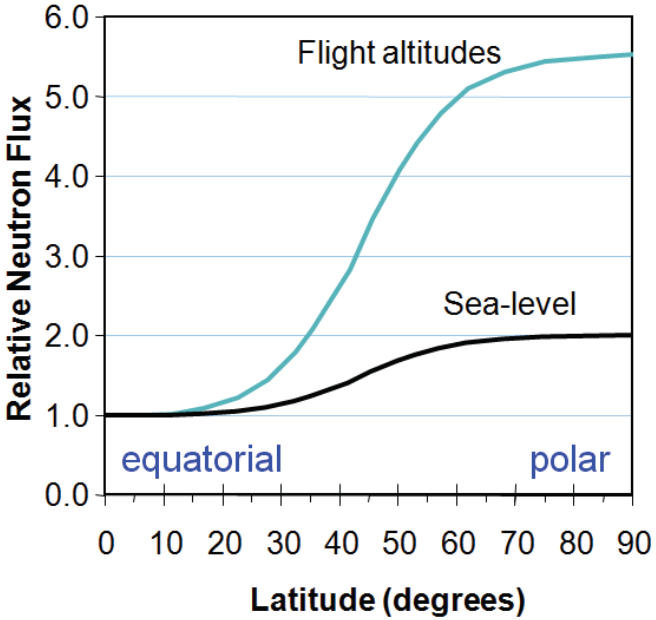
Neutron Ground-Level Enhancements (GLEs)

- During the 11-year solar cycle, the Sun sometimes emits particles of sufficient energy and intensity to raise radiation levels on Earth's surface – *i.e.*, GLE.
- Detected using ground-based neutron monitors, like the one at McMurdo Station in Antarctica.
- University of Oulu, Finland maintains the International GLE Database (http://gle.oulu.fi/).
  - 71 GLEs in the database currently



R. C. Baumann, *IEEE NSREC Short Course*, San Francisco, CA, 2013.

Nominal Conditions



M. S. Gordon, *et al.*, *IEEE Trans. Nucl. Sci*, vol. 51, Dec. 2004.

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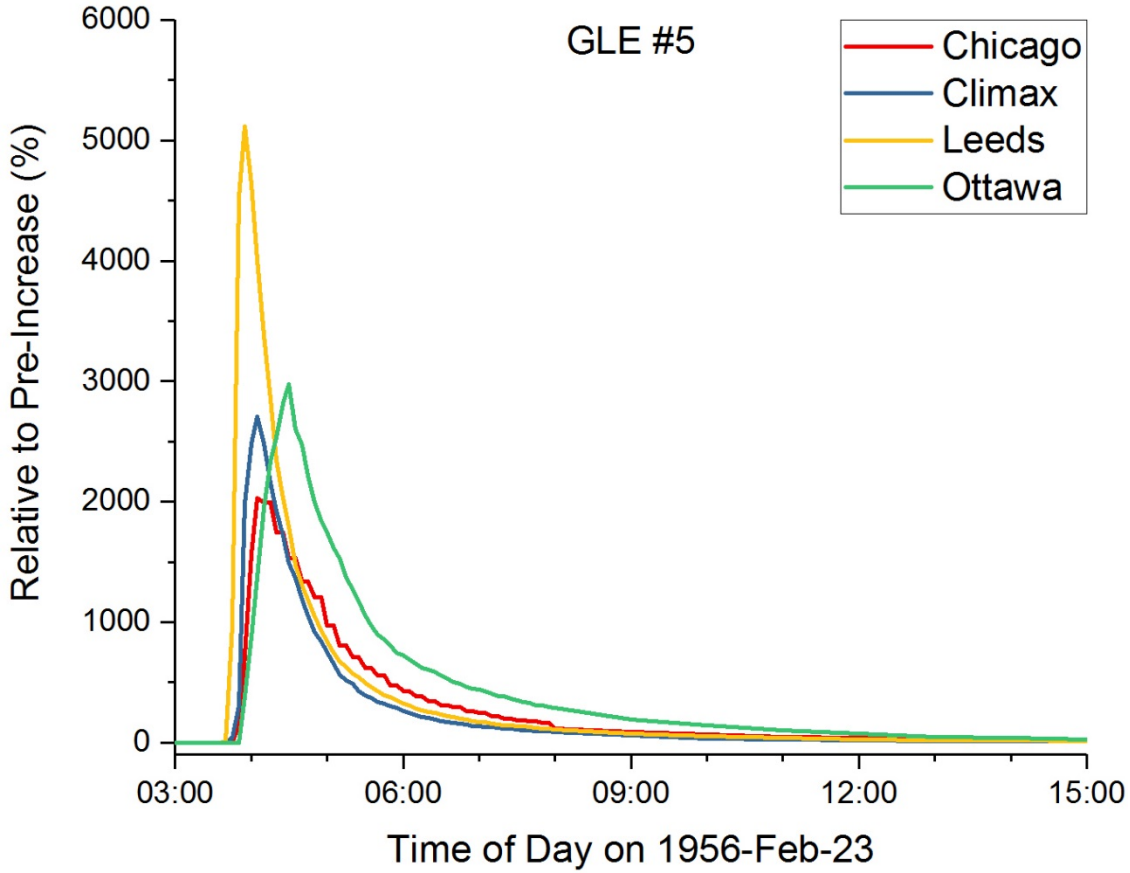
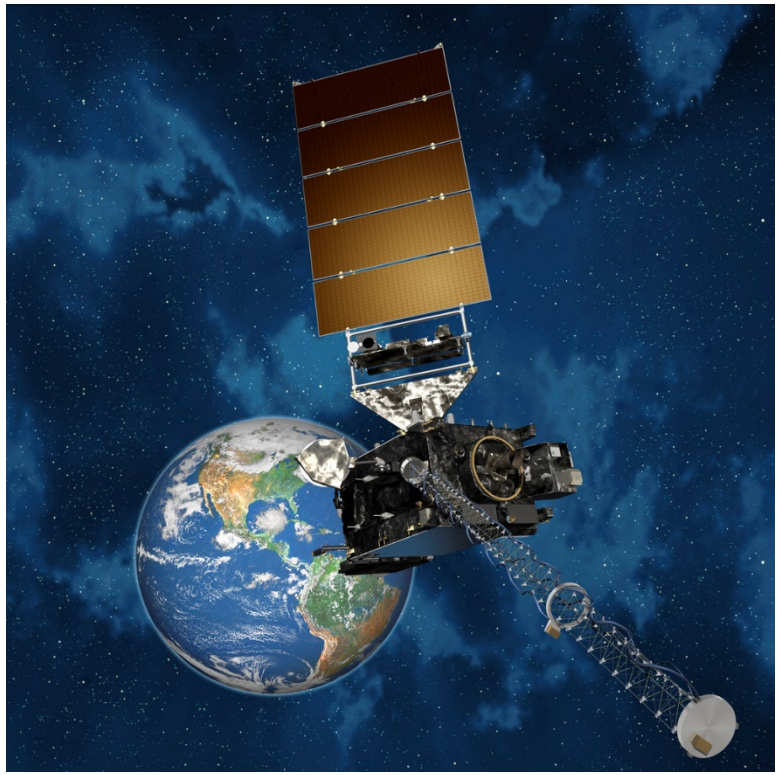
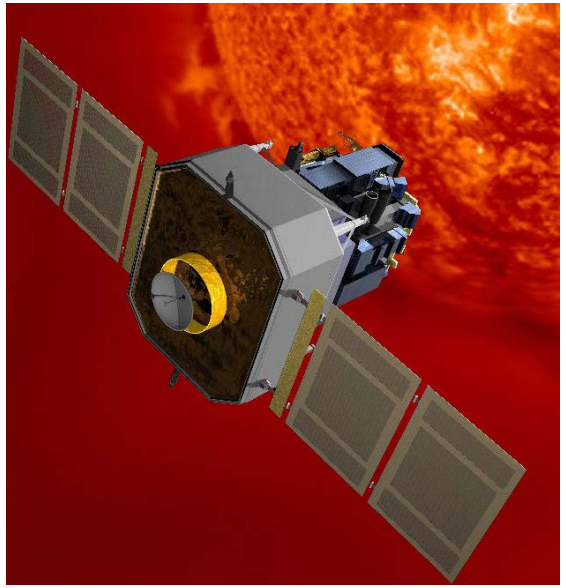


University of Oulu, Finland, International GLE Database (http://gle.oulu.fi/)

Measuring Space Weather



Geostationary Operational Environmental Satellite — R Series (GOES-16)
A collaborative program of NOAA and NASA

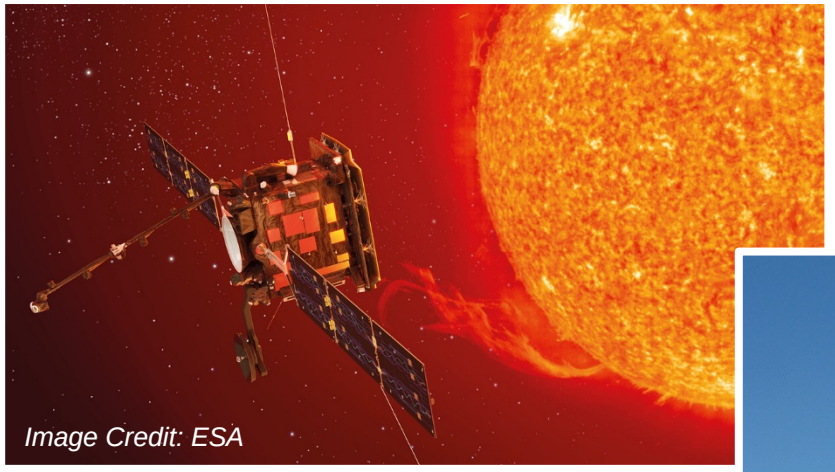


Solar and Heliospheric Observatory (SOHO); image credit, NASA.
SOHO is a project of international cooperation between ESA and NASA.

McMurdo Neutron Monitor
Image courtesy of
University of Delaware, Bartol Research Institute
Neutron Monitor Program

Examples of current NASA space weather research missions: the **Advanced Composition Explorer** and NOAA's **Deep Space Climate Observatory** observe the solar wind; the **Solar Dynamics Observatory**, the **Solar and Terrestrial Relations Observatory**, and the joint ESA/NASA **Solar and Heliospheric Observatory** all observe solar eruptions on the Sun; and the **Van Allen Probes** observe the radiation belts around Earth.

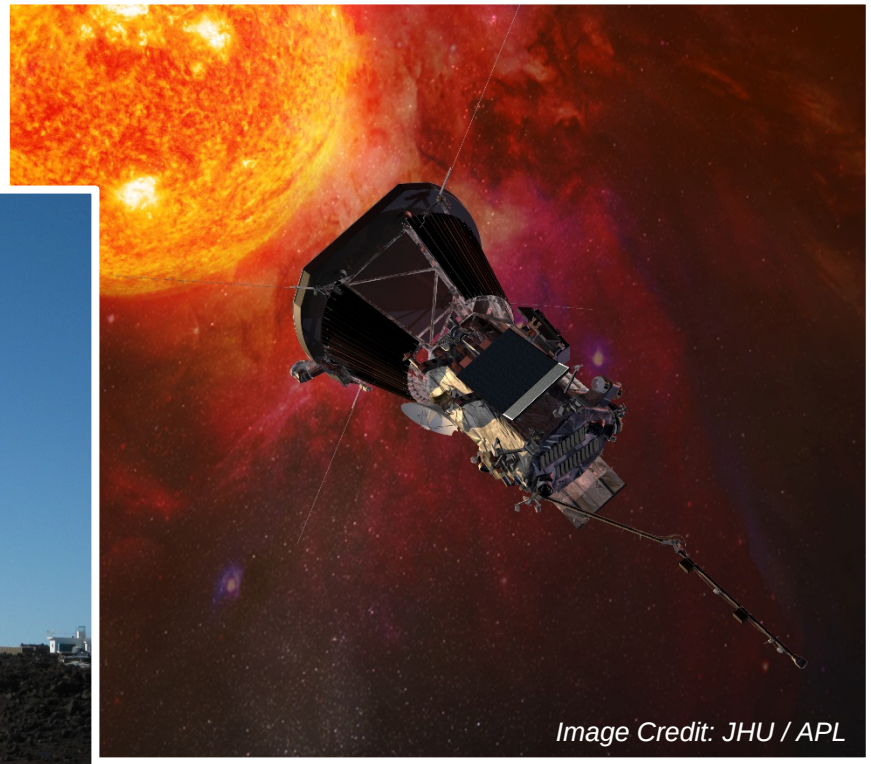
Future of Space Weather Measurements



ESA Solar Obiter

- Solar magnetism
- Model and predict

Daniel K. Inouye Solar Telescope (DKIST)



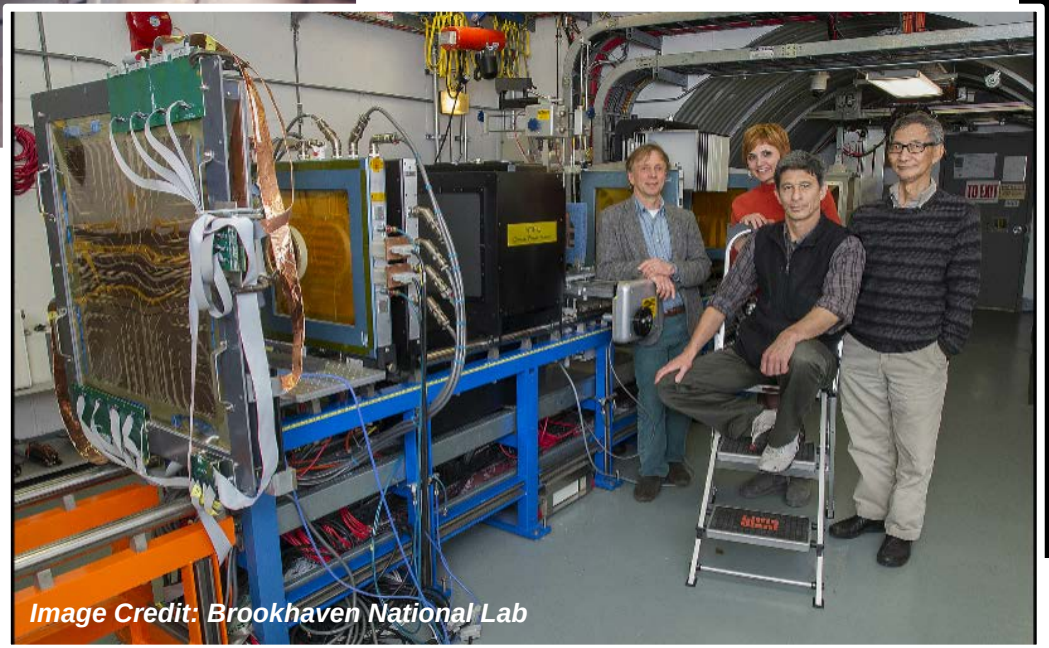
NASA Solar Probe Plus

- Solar wind
- Solar dynamo
- Energy flow

- Heating and acceleration of corona
- Transport of energetic particles

Understanding and Mitigating Space Weather Hazards

Texas A&M K500 Cyclotron



NASA Space Radiation Laboratory, Brookhaven National Lab

Simulation of 1 EeV (10^{18} eV!) proton air shower

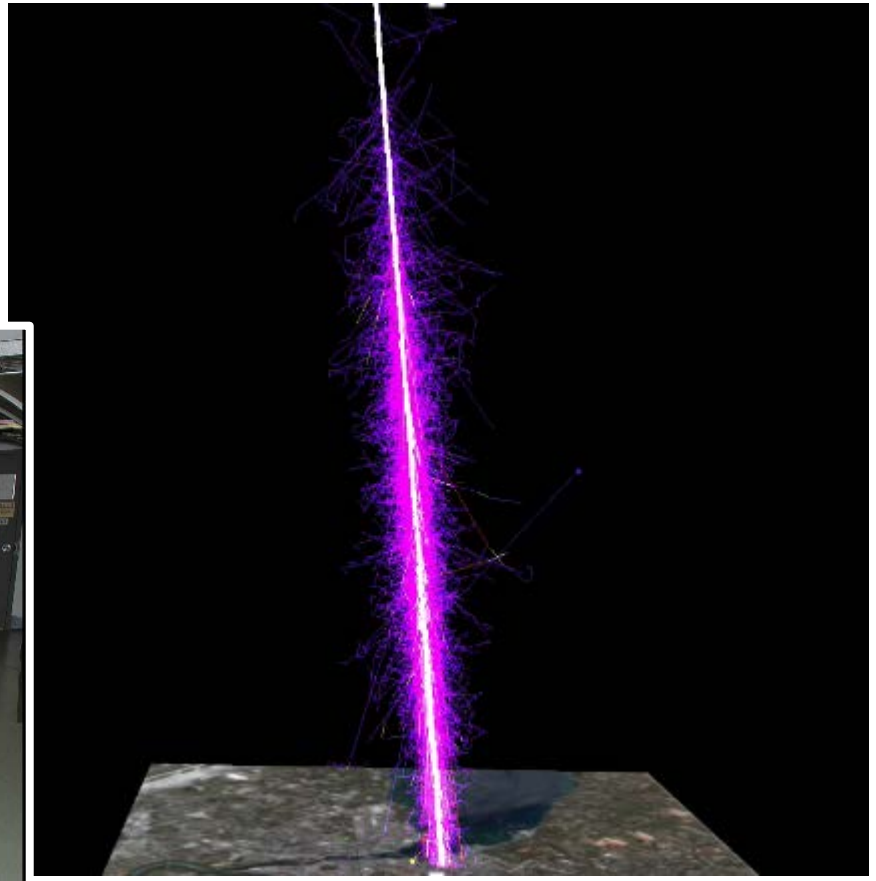


Image credit: University of Chicago & Sergio Sciutto for AIRES

Policies to Mitigate Space Weather Hazards

National Space Weather Strategy
National Space Weather Action Plan
National Science and Technology Council, October 2015

Coordinating Efforts to Prepare the Nation for Space Weather Events
Executive Order, October 2016

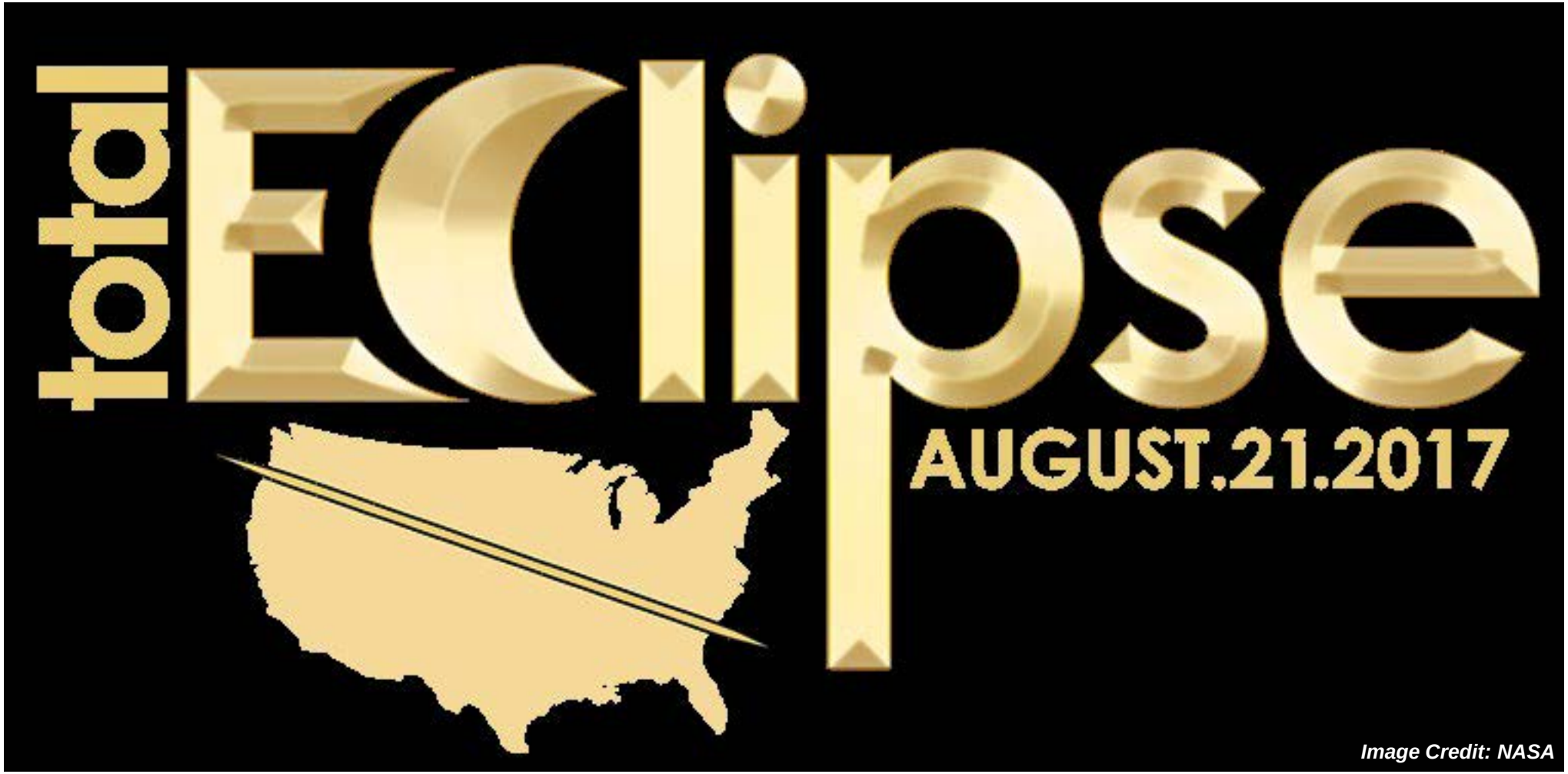
Many other departments, agencies, and service branches involved

Restart vs. Rebound

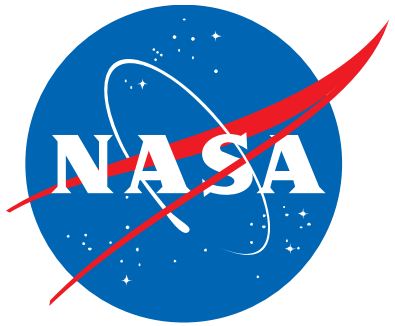
Summary

- The Sun and the Sun-Earth connection drive space weather
- Space weather hazards can originate directly from material ejected by the Sun or indirectly through secondary processes (*e.g.*, atmospheric neutron generation)
- Measuring, understanding, modeling, and predicting space weather is a significant challenge requiring commitments and collaboration at the nation-state level
- Future investments, like DKIST, Solar Orbiter, and Solar Probe Plus will yield the knowledge necessary to better predict space weather
- National policies and action plans help facilitate actions to protect space- and ground-based technology and infrastructure

2017 Solar Eclipse



https://eclipse2017.nasa.gov/


NASA

Appendix: Acronyms

ACE	Advanced Composition Explorer
AIA	Atmospheric Imaging Assembly
AIRES	AIRshower Extended Simulations
AURA	Association of Universities for Research in Astronomy
CME	Coronal Mass Ejection
DKIST	Daniel K. Inouye Solar Telescope
DSCOVR	Deep Space Climate Observatory
ESA	European Space Agency
EVE	Extreme Ultraviolet Variability Experiment
GCR	Galactic Cosmic Ray
GLE	Ground-Level Enhancement
GOES	Geostationary Operational Environmental Satellite
HMI	Helioseismic and Magnetic Imager
IEEE	Institute of Electrical and Electronics Engineers
JHU / APL	Johns Hopkins University / Applied Physics Laboratory
LASCO	Large Angle and Spectrometric Coronagraph
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NSO	National Solar Observatory
NSREC	Nuclear and Space Radiation Effects Conference
SDO	Solar Dynamics Observatory
SOHO	Solar and Heliospheric Observatory
STEREO	Solar Terrestrial Relations Observatory
SWx	Space Weather